AD/A-006 229

MANIPULATING THE NUMBER AND TYPE OF ADAPTIVE VARIABLES IN TRAINING

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Prepared for:

Air Force Office of Scientific Research

October 1974

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFOSR - TR - 75 - 0302	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER AD/A -00 6229
4. TITLE (and Subtitle) Manipulating the Number and Type of Adaptive Variables in Training		5. TYPE OF REPORT & PERIOD COVERED Scientific Interim
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Daniel Gopher, Beverly H. Williges, Robert C. Williges, and Diane L. Damos		8. CONTRACT OR GRANT NUMBER(s) F44620-70-C-0105
9. PERFORMING ORGANIZATION NAME AND ADDRESS Aviation Research Laboratory Institute of Aviation University of Illinois, Savoy, Illinois 61874		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 9778 61102F 681313
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Office of Scientific Research 1400 Wilson Boulevard (NL) Arlington, VA 22209		12. REPORT DATE October 1974
		13. NUMBER OF PAGES 12
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Adaptive Training
Tracking Performance
Control Theory

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Abstract (continued)

fixed or adaptive. A transfer and retention task in which the tracking situation changed periodically was used to evaluate the ability of subjects to adjust to change. Each adaptive variable in training was analyzed separately. With gain more adaption occurred when gain was associated with another adaptive variable. In frequency the highest rate of adaption occurred with frequency alone. In acceleration the rate of adaption was greater early in training when frequency also adapted. During transfer subjects trained adaptively generally showed more stable performance in the changing task situation. No reliable differences among conditions appeared in retention. Results are discussed in terms of stimulus and response similarity, the optimum number of adaptive variables, and the appropriateness of a changing task to evaluate adaptive training.

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TECHNICAL REPORT

ARL-74-12/AFOSR-74-7
OCTOBER 1974

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To investigate the effectiveness of various types and numbers of adaptive variables, 48 subjects performed a two-dimensional pursuit tracking task for five three-minute training sessions. In the factorial design resulting in eight experimental conditions, three variables (frequency of the forcing function, ratio of acceleration to rate control, and the amount of gain in the control stick) were either fixed or adaptive. A transfer and retention task in which the tracking situation changed periodically was used to evaluate the ability of subjects to adjust to change. Each adaptive variable in training was analyzed separately. With gain more adaption occurred when gain was associated with another adaptive variable. In frequency the highest rate of adaption occurred with frequency alone. In acceleration the rate of adaption was greater early in training when frequency also adapted. During transfer subjects trained adaptively generally showed more stable performance in the changing task situation. No reliable differences among conditions appeared in retention. Results are discussed in terms of stimulus and response similarity, the optimum number of adaptive variables, and the appropriateness of a changing task to evaluate adaptive training.

INTRODUCTION

Interest in the use of automatically adaptive techniques is on the increase primarily because such techniques might provide an optimum learning model to teach psycho-motor skills. Adaptive training is a closed-loop system in which some aspect of student performance (system output) is measured and used to set the level of the training problem (system input). Generally a computer algorithm determines the precise relationship between the adaptive variable and the performance measurement. (See Kelley, 1969a, for a complete discussion of adaptive and fixed training methods.)

Conceivably any aspect of the system that affects output behavior might be selected as the adaptive variable. However, the results of a recent study by Crooks (1973) imply that the use of certain adaptive variables may establish an interference paradigm. Crooks used the velocity/acceleration ratio of the control dynamics as the adaptive variable in a two-dimensional, compensatory tracking task. Three of the four adaptive training groups required more time to attain the learning criterion than did a fixed-difficulty group. These results are in sharp contrast to an earlier study by Lowes, Ellis, Norman, and Matheny (1968) in which turbulence was used as the adaptive variable and adaptive training was clearly superior. Crooks (1973) reasoned that, because large, slow control movements were optimum when the percentage of acceleration was small whereas small quick control movements were best when a larger amount of acceleration control was present, his adaptive training groups had been required to make different responses to similar or identical stimuli as training progressed.

According to Osgood's transfer surface (1953) the pairing of dissimilar responses to similar stimuli interferes with learning and results in negative transfer. The Crooks (1973) data agree with this generalization. On the other hand, Osgood also suggested that changing the stimulus and requiring a similar response does not result in negative transfer. The present study was designed to use adaptive variables that primarily are either stimulus or response variables to determine if the degree of original learning and transfer in adaptive training is compatible with the predictions of Osgood's transfer surface. In addition, the velocity/acceleration ratio of the control dynamics was also used as an adaptive variable to replicate the Crooks (1973) study and compare these results to those obtained by adopting specific stimulus and response variables.

To date, research comparing adaptive training to fixed-variables training has viewed these two types of training as completely separate entities. A task was considered to be fixed if all its parameters were predetermined and fixed throughout the experiment or was considered to be adaptive if one of the variables was manipulated adaptively. This approach ignores the fact that for almost any given task a number of variables may be selected to adapt or to be defined and maintained at a fixed level. An alternative approach is to regard fixed and adaptive training as end points of a continuum. The various points along this continuum are defined by the number of variables adapted simultaneously. Such an approach enables the comparison of fixed-variables tasks with adaptive tasks that lie at different points along the fixed/adaptive continuum. It also permits the comparison of different adaptive situations among themselves.

Another research issue in this study involves determining a relevant task to validate original learning in adaptive training situations. The evaluation of adaptive training using transfer tasks typically has involved a fixed-level criterion task (Crooks, 1973; Lowes, Ellis, Norman, and Matheny, 1968; Norman, Lowes, and Matheny, 1972; Wood, 1969). Although such a validation is important and useful, it may fail to reflect an important characteristic of adaptive techniques, namely that adaptive training involves a changing task situation such as the different control orders a pilot uses in changing from normal flight to slow flight. It is possible that this unique characteristic facilitates the future adjustment of subjects to changing task situations. A task that requires subjects to perform under varying conditions may constitute a very important and meaningful validation situation for the effects of adaptive training.

In view of these questions the present study employed three types of adaptive variables representing different stimulus and response characteristics in a two-dimensional pursuit tracking task. These variables were the frequency of the forcing function, the control stick sensitivity, and the order of system control (percent of second-order integrations). Forcing function frequency represented manipulation of the stimulus aspects of the tracking display, whereas control stick sensitivity and control order represented different manipulations of the response aspects of the tracking task.

Each of these variables was either maintained at a constant level or allowed to adapt during training. The resulting between-subjects factorial combination of these three variables yielded eight treatment conditions consisting of a control condition with no adaptive variables, three conditions in which only one variable adapted, three conditions in which two variables adapted, and one condition in which all three adapted. Performance was evaluated in original learning, transfer, and retention. In both transfer and retention, the subjects were required to perform a tracking task which periodically changed in terms of task demands. In summary, the present study was designed to investigate the implications of adapting stimulus and response variables, the effect of varying the number of adaptive variables, and the usefulness of adaptive techniques in training for transfer to changing task conditions.

METHOD

Subjects

A total of 48 subjects, 36 males and 12 females, participated in the present experiment. Subjects were university students enrolled in a summer flight training course at the Institute of Aviation or were participating in an experimental flight training program at the Aviation Research Laboratory. Six subjects were randomly assigned to each of the eight experimental conditions.

Apparatus

The basic experimental equipment included a 3 x 4 in. Hewlett-Packard Model 1300 CRT display and a spring-centered dual-axis hand control. A Raytheon 704 16-bit digital computer with 24K memory was used both to generate inputs for the CRT through a symbol generator and to process signals from the subjects through an analog to digital converter.

Experimental Task

Subjects performed a two-dimensional pursuit tracking task. The horizontal and vertical axes were manipulated independently, and two independent, random, band-limited, forcing functions were generated for changing the position of the forcing function symbol on the CRT display. An "X" symbol was used to signify the forcing function, while an "O" symbol represented the stick output. The effective screen size for the movement of these symbols was 7.6 x 7.6 cm., and the symbols were contained within a .55 x .40 cm. square. A 60msec. cycle was used for the execution of the experimental program and the refreshment of the display.

Experimental Design and Adaptive Logic

A three-factor, between-subjects design was used in which each independent variable either remained fixed during training or adapted. The first variable was the forcing function frequency (Hz) which was manipulated by increasing the upper cutoff frequency of the limited-band, low-pass filters. The second variable was the gain output of the control stick which was increased relative to the effective size of the display. A direct transformation of this value to Hz may be obtained through the equation,

$$.52G = Hz \qquad (1)$$

where G is the specific scale gain value. The third variable was the second-order term of the control output which was changed through the equation,

$$\theta_o = (1 - \alpha)\frac{K}{S} + \alpha\frac{K}{S^2} \qquad (2)$$

where θ_o equals the order of the control system, K is a gain constant, S is the Laplace transform, and α is the percent acceleration. The usefulness of this adaptive variable has been demonstrated previously (Crooks and Roscoe, 1973; Gopher and North, 1974).

An almost continuous, small-step adaptive logic was used to manipulate the independent variables during the training sessions. Tracking error was computed within the 60 msec. cycle, and the variables levels were changed in a .0005 step size. The tolerance limit for tracking error on both axes was .10 of scale absolute error. The two axes were measured and adapted independently using the same adaptive logic.

Procedure

Training. The inclusion of eight different experimental combinations and the independent manipulations of the two axes in the training sessions did not enable the use of the popular time-to-exit criterion measure as the dependent variable for the evaluation of training effectiveness. To define a reasonable exit criterion would have required a full-scale experiment to explore the various interactions between variables and axes. Instead all groups received a fixed period of training, and the levels of the adaptive variables were used as the dependent measure.

To determine the fixed values for nonadaptive variables in the different training conditions, a preliminary study was conducted. This study included a group of five flight-naive subjects representative of the experimental population and a group of five experienced pilots. Both groups performed the task with all three variables adapting for four sessions of five minutes each. The results indicated a clear superiority of the experienced pilots over the flight-naive subjects with very little overlap between the two distributions. In view of these results, the average levels of the naive group on the fourth trial were used as the fixed values for the three independent variables in the various training conditions. The fixed values for the three variables were:

	Horizontal Axis	Vertical Axis
Acceleration	.350	.240
Frequency	.370	.260
Gain	.750	.640

The initial values for the three variables in the adaptive conditions were 0.0 for percent acceleration, .020 Hz for frequency, and .40 for gain. One reason for the selection of a higher value for the gain variable was to enable effective tracking when the forcing function was fixed. Another consideration was the U-shaped relationship between gain and difficulty for a specific value of frequency. The U shape is created because difficulty is decreased from the point of undersensitivity to the point of optimal sensitivity and increased again towards the oversensitivity side of the function.

All subjects were trained for five periods of three minutes each with three-minute breaks between periods. Each period was started at the final level of the previous period and was terminated automatically by the computer. A 30-minute break separated the training from the transfer sessions. During this break subjects received a short questionnaire in which they were asked to rate the difficulty of the tracking task and to evaluate their performance.

Transfer. The experimental setup for the transfer task was identical to that of the original training. However, the task structure was changed. The task involved eight minutes of continuous tracking, comprised of four two-minute sections. Although the levels of the three independent variables were fixed within sections, they varied among sessions. The specific combinations for each of the four sections represented the average last session values of the three variables, obtained by the two best naive subjects and the two poorest experienced pilots in the preliminary experiment. These values represent, on the average, an increase in difficulty from the training to the transfer situation. The four sections were randomly combined but presented in the same order to all subjects. No warning or prior instructions were given as to the change of values in the different sections.

Retention. Except for the reshuffling of the order of the four sections, the retention task was equivalent to the transfer task. Subjects performed the retention task approximately one week after the transfer session, although due to scheduling difficulties a few subjects did not complete the retention task until three weeks after transfer.

RESULTS

Training

A direct comparison of the eight experimental conditions in training was not possible because they differed in the specific dependent measures employed. For the fixed-variables condition root mean square (RMS) tracking error was obtained. For the three experimental conditions involving at least one adaptive variable, performance was evaluated in terms of the changing level of each of the variables adapting. As a result separate analyses were conducted for the fixed-variables conditions and for each of the three adaptive variables. Within each of these analyses performance was evaluated separately for the horizontal axis, the vertical axis, and a combined score on the two axes.

Fixed-variables training. Figure 1 presents the learning curves of the fixed-variables group for each axis. The figure indicates an ordered and reliable decrease of RMS error on both axes as a result of training, $F(4, 20) = 16.37$, $p < .001$. No reliable differences were found between RMS errors on the two axes, despite the seemingly higher average tracking error on the vertical axis in the first session ($p > .05$). The similarity of the tracking error scores on the two axes is very important in view of the much lower values of the experimental variables on the vertical axis. These values were suggested by the preliminary study which demonstrated a clear superiority of tracking performance on the horizontal as compared with the vertical axis. The different fixed values were selected in an effort to equalize the two axes in terms of difficulty. The tracking performance of the fixed-variables group indicates the success of this effort.

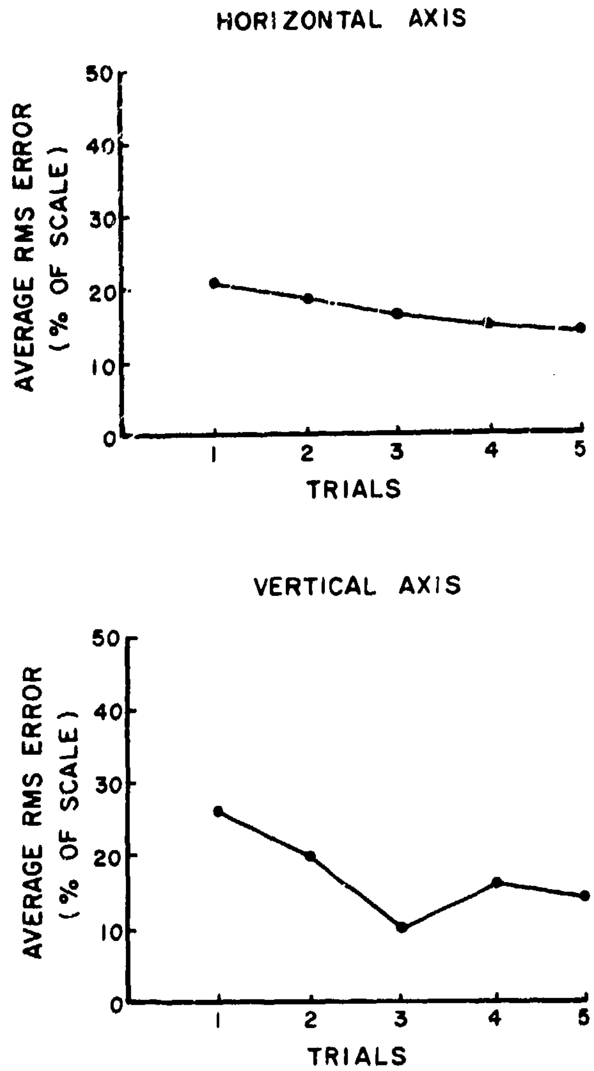

Figure 1. Average RMS tracking error (percentage of scale) in the horizontal and vertical axes for the fixed-variables condition during each trial of the training session.

Adaptive training. Figure 2 presents the average level of the three adaptive variables during each of the five training sessions. The figure presents the results separately for each axis using the four unique experimental combinations of each adaptive variable. These between-subjects analyses were considerably limited in terms of sensitivity by the small number of subjects in each condition and the large inter-subject variability in tracking ability. Nevertheless, a number of differences proved to be statistically reliable. As shown in Figure 2, all the experimental combinations produced the expected increment in the values of the adaptive variables during the training sessions. However, there is a considerable variation in the slopes and general shape of these curves. The analysis of variance for both axes indicated highly significant values both for trials and for intervals within trials on all the adaptive variables.

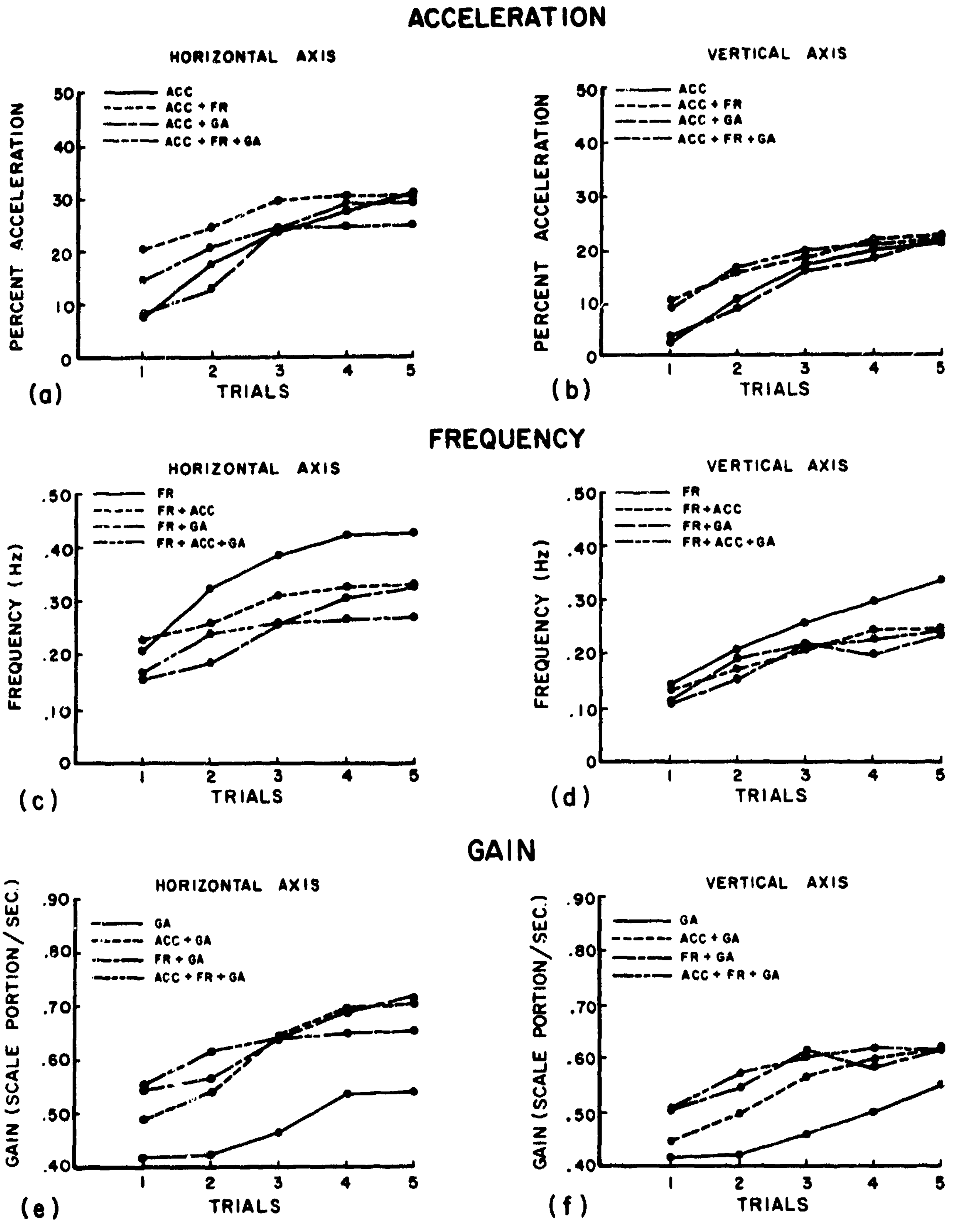

Figure 2. Average levels of adaptive variables during each trial of the training session.

When gain was used as an adaptive variable, the level of adaption was higher when gain was associated with another adaptive variable as compared to the condition in which gain alone adapted, $F(3, 20) = 3.43$, $p < .04$. The same general trend appeared on the vertical axis but was not statistically reliable ($p > .05$) primarily as a result of the generally lower level of performance on this axis.

The results of the analysis involving frequency of the forcing function as an adaptive variable did not yield significant main effects of experimental conditions, but the interaction of Conditions x Trials was highly significant for both the horizontal axis and the summative value of both axes, $F(12, 80) = 3.82$, $p < .001$ and $F(12, 80) = 3.17$, $p < .001$, respectively. On the vertical axis, a significant Conditions x Trials x Intervals within Trials interaction was observed, $F(24, 160) = 1.62$, $p < .05$. As indicated in Figures 2c and 2d this significant interaction resulted from the increasing superiority of the frequency only condition during the last three trials of the training session.

The analysis dealing with the percentage of acceleration control also revealed no significant main effect. But here again, a highly significant interaction of Conditions x Trials appeared on the horizontal axis, $F(12, 80) = 2.68$, $p < .004$. An examination of Figures 2a and 2b reveals that the major differences occurred in the first two training trials where subjects in the acceleration and in the acceleration plus gain conditions were at much lower levels of the adaptive variable than subjects in the conditions that included frequency as an adaptive variable.

Table 1 summarizes the average level of the adaptive variables for each of the eight experimental conditions during the last minute of original learning. Both fixed and adaptive values are presented.

TABLE 1

Average levels of the experimental variables on the last minute of training.

Experimental Condition	Acceleration	Frequency	Gain
Horizontal Axis			
Fixed Variables	.350*	.370*	.750
Acceleration	.323	.370*	.750*
Frequency	.350*	.428	.750*
Gain	.350*	.370*	.533
Acceleration + Frequency	.311	.331	.750*
Acceleration + Gain	.289	.370*	.689
Frequency + Gain	.350*	.337	.717
Acceleration + Frequency + Gain	.270	.290	.669
Vertical Axis			
Fixed Variables	.240*	.260*	.640*
Acceleration	.235	.260*	.640*
Frequency	.240*	.339	.640*
Gain	.240*	.260*	.573
Acceleration + Frequency	.246	.266	.640*
Acceleration + Gain	.251	.260*	.651
Frequency + Gain	.240*	.252	.632
Acceleration + Frequency + Gain	.203	.223	.602

* Fixed Level

The values presented indicate that the only condition in which subjects achieved higher values on both axes as compared with the fixed-variables group occurred when frequency alone adapted. When frequency and acceleration or when acceleration and gain were adapted, levels higher than those of the fixed-variables group were obtained on the vertical axis only.

For adaptive training groups the comparison of tracking performance on the two axes revealed that despite the effort to use lower fixed values on the vertical axis, subjects generally demonstrated poorer performance on this axis. Of the 42 subjects in the seven adaptive conditions, 31 obtained higher averages on the horizontal axis $\chi^2 (1) = 4.878$, $p < .05$). These differences can be observed clearly in Figure 2. The largest and statistically most reliable differences were obtained for the frequency only condition, $t (5) = 2.70$, $p < .05$; the frequency plus gain condition, $t (5) = 5.76$, $p < .01$; and the frequency plus acceleration condition, $t (5) = 3.37$, $p < .02$. The analysis of results for the frequency-adapted groups also indicated a reliable tendency for an increase in the difference between the two axes within each of the five training trials, $F(2, 40) = 5.454$, $p < .01$. This increase implies that the two axes differed in the rate of progress on the adaptive variables. A similar trend was found for the acceleration-adapted group but was reliable only for the first and the third trials, $F(8, 160) = 2.382$, $p < .02$. Performance on the two axes was most similar on the gain only condition, primarily as a result of the generally lower performance in this condition.

Subjective ratings. In a short questionnaire that followed the training session subjects were asked to evaluate on a six-point scale the difficulty of the tracking task and their performance. Despite the objective differences between the experimental conditions in the general level of performance and learning curves, no differences were found in the rating of subjective difficulty or the self-evaluation of performance. The average rating for difficulty was 2.68 with a standard deviation of .85. This average indicates that the experimental conditions in general were perceived as slightly above average in difficulty. The average for the self rating of performance was 3.24 with a standard deviation of 1.001 which indicates a moderate satisfaction of subjects with their performance.

Transfer

Two major comparisons among the eight experimental conditions were made with regard to transfer-task performance. The first analysis involved tracking error averaged over 15-second intervals throughout the task. The second analysis compared within-subject differences in tracking error computed between the last 15 seconds of each task section and the first 15 seconds of the following section. The second analysis was used to examine the assumption that subjects trained adaptively would exhibit less variability in tracking error as a result of changes in the tracking situation.

Overall RMS tracking error. Table 2 presents the levels of the experimental variables in each of the four sections of the transfer task. Table 3 presents average RMS error for each experimental condition during each section of the transfer task. Separate analyses of variance were conducted for each tracking axis and the sum of the two axes.

In both axes separately and combined, the results indicated the expected reliable effects of Sections, $p < .001$, and Sections x Intervals, $p < .001$. However, because the

TABLE 2

Levels of the Experimental Variables Maintained during Each Section of the Transfer Task

Variable	Section 1	2	3	4
	Horizontal Axis			
Acceleration	.45	.43	.37	.40
Frequency	.47	.44	.39	.42
Gain	.85	.82	.77	.80
	Vertical Axis			
Acceleration	.24	.33	.29	.28
Frequency	.26	.35	.31	.30
Gain	.64	.73	.69	.69

TABLE 3

Average RMS Tracking Error (Percentage of Scale) in the Horizontal and Vertical Axes for Each Experimental Condition during Each Section of the Transfer Task

Experimental Condition	Section 1	2	3	4	$\bar{X}$
	Horizontal Axis				
Fixed Variables	18.0	16.9	15.4	16.1	16.6
Acceleration	18.5	18.1	15.8	18.0	17.6
Frequency	16.7	16.2	15.2	15.8	16.0
Gain	18.1	17.3	16.2	17.2	17.2
Acceleration + Frequency	18.9	19.2	16.1	18.7	18.2
Acceleration + Gain	18.9	18.0	16.1	18.2	17.8
Frequency + Gain	21.6	21.8	19.5	18.6	20.4
Acceleration + Frequency + Gain	21.8	21.4	21.0	21.2	21.3
$\bar{X}$	19.1	18.6	16.9	18.0	18.1
	Vertical Axis				
Fixed Variables	14.8	16.5	15.1	14.5	15.2
Acceleration	16.5	18.2	16.0	18.3	17.3
Frequency	14.7	16.4	16.6	15.1	15.8
Gain	16.6	16.9	18.3	16.8	17.2
Acceleration + Frequency	14.8	17.8	16.8	17.1	16.6
Acceleration + Gain	16.6	17.4	15.7	17.6	16.8
Frequency + Gain	20.3	20.7	19.3	18.3	19.6
Acceleration + Frequency + Gain	17.8	20.7	21.8	19.1	19.9
$\bar{X}$	16.5	18.1	17.5	17.2	17.3

order of presentation of sections was fixed for all subjects, no distinction can be drawn between the effects due to order of presentation. An additional complication in interpreting those reliable effects involving sections results from the direct use of adaptive levels obtained by subjects in the preliminary study to set the values for various sections in the transfer task. As shown in Table 2 the spacing between values used was uneven, and the relative emphasis on the horizontal or vertical axis varied across sections.

On the vertical axis additional reliable interactions included Acceleration x Sections, $F(3, 120) = 2.89$, $p < .04$, and Acceleration x Frequency x Sections, $F(3, 120) = 3.07$, $p < .04$. These interactions were due primarily to the higher error scores for the second and fourth sections in the acceleration combinations and lower error on the first section of the acceleration plus frequency conditions. No reliable differences between groups were found on the horizontal axis. However, gain-adapted groups generally obtained higher error scores, and this tendency approached the common level of reliability, $F(1, 40) = 3.914$, $p = .0548$. The Acceleration x Sections interaction was also reliable for the summative values of the two axes, $F(3, 120) = 3.11$, $p < .03$.

Difference scores. The analysis of difference scores comparing the last 15 seconds of each section to the first 15 seconds of the following section yielded a number of reliable differences each indicating that the subjects trained adaptively had less difficulty transitioning among the various sections of the transfer task. Subjects trained with frequency adapting performed significantly better during transition periods than did other subjects on both the horizontal axis, $F(1, 40) = 6.54$, $p < .02$, and the vertical axis, $F(1, 40) = 11.18$, $p < .01$. In addition, on the vertical axis subjects trained with gain adapting performed significantly better than subjects in conditions where gain did not adapt, $F(1, 40) = 4.15$, $p < .05$.

Retention

Both the overall analysis of RMS error and the analysis of difference scores were performed on retention data. Table 4 presents mean tracking error for each condition by axis and task section. In general few reliable differences among the eight experimental conditions were found. However, the interaction between gain and task section was significant on the horizontal axis of the overall analysis of RMS error, $F(3, 120) = 7.80$, $p < .001$, and for the summative value of both axes, $F(3, 120) = 2.90$, $p < .04$. Groups in which gain adapted obtained higher error scores in the second and fourth sections of the retention task. These sections correspond to Sections 4 and 2 in the transfer task and included the higher levels of the adaptive variables.

DISCUSSION

Independent Manipulation of Axes

The performance of subjects on the two-axis pursuit tracking task during training justified the initial decision to manipulate and measure each of the axes separately. Tracking performance on the vertical axis was consistently inferior to the horizontal axis and produced adaptive curves of lower rates for both frequency- and acceleration-adapted groups. The lower performance on the vertical axis can be interpreted along the compatibility dimension (Fitts and Posner, 1967), because the vertical movements of the forcing function symbol

TABLE 4

Average RMS Tracking Error (Percentage of Scale) in the Horizontal and Vertical Axes for Each Experimental Condition during Each Section of the Retention Task

Experimental Condition	Section 1	2	3	4	X̄
Horizontal Axis					
Fixed Variables	16.0	16.9	14.6	15.1	15.6
Acceleration	16.6	17.3	15.4	15.5	16.2
Frequency	16.6	16.8	14.7	15.6	15.9
Gain	17.2	16.7	15.4	17.5	16.7
Acceleration + Frequency	19.4	19.3	18.3	18.2	18.8
Acceleration + Gain	16.2	17.8	15.3	18.6	17.0
Frequency + Gain	18.3	19.8	16.5	20.5	18.8
Acceleration + Frequency + Gain	19.7	21.1	18.7	19.9	19.9
X̄	17.5	18.2	16.1	17.6	17.4
Vertical Axis					
Fixed Variables	14.1	16.3	14.5	13.0	14.5
Acceleration	15.9	17.7	15.1	14.7	15.8
Frequency	16.0	16.1	15.1	13.5	15.2
Gain	16.5	17.0	15.0	15.0	15.9
Acceleration + Frequency	17.5	19.7	16.9	15.8	17.5
Acceleration + Gain	15.7	16.7	16.2	15.8	16.1
Frequency + Gain	18.6	18.6	17.8	16.1	17.5
Acceleration + Frequency + Gain	19.3	20.1	17.8	16.7	18.5
X̄	16.7	17.8	16.1	15.1	16.4

had to be translated by the subject to an orthogonal fore and aft movement of the control stick. No such translation was required for the horizontal axis.

The differences between the axes raise several important questions in view of the widespread usage of similar task configurations in flight training, simulation, and research. It is apparent that the conventional, combined-axes scoring techniques such as averaging, vector values, or largest-error scores (see Kelley, 1969b, for a comprehensive discussion of tracking-scoring techniques) consistently provide underestimates of one axis or overestimates of the other. In adaptive configurations these errors lead either to a too rapid or too slow rate of change of the adaptive variable with regard to the momentary level of proficiency. In control system evaluation it may increase errors of prediction which could be reduced by deriving separate equations for each axis.

In turn, independent manipulation of axes raises several questions that require systematic investigation in further research. One question concerns the evaluation of the relative difficulty of various task configurations; that is, the effects of an increase or decrease on one axis as compared to similar changes on the other. Another question is whether a symmetrical, equal-weight or an asymmetrical, differential-weight adaptive logic is more appropriate in multi-axes training. Attention also should be directed to the investigation of techniques for sequentially manipulating the axes as compared with simultaneous manipulation of axes.

Type and Number of Adaptive Variable

In general, the experimental findings agree with the Osgood (1953) surface and suggest that stimulus rather than response variables are to be recommended in adaptive training when the goal is to optimize the rate of adaption during training. The highest rate of adaption using a stimulus variable (forcing function frequency) occurred when it was the only adaptive variable. In addition, rate of adaption of the two response-related variables (control stick gain and acceleration percentage) was facilitated when the stimulus variable also adapted. Manipulation of response variables may even result in inhibitive effects.

Adapting the percentage of acceleration control did not clearly facilitate rate of adaption during training. In terms of transfer, there was some indication that training with acceleration percentage adapting resulted in poorer tracking performance on certain segments of the transfer task. These results support Crook's (1973) data which indicate that acceleration percentage may not be a fruitful adaptive variable. With the pursuit tracking task used in this study as compared to the compensatory task used by Crooks, the subjects could clearly see that the response element ("0") was affected by adaption and not the stimulus element ("X"). But, the displayed effect is not straightforward, because an identical response pattern yielded a dissimilar visual display when the acceleration percentage adapted. This rather devious relationship appeared to interfere with transfer. However, in many real systems adapting the control order occurs. Additional research is needed to determine effective techniques to train individuals to cope with slow and rapid changes in the control system.

Clearly, more adaption in gain occurred when other variables also adapted. When it appeared alone, rate of adaption in gain was markedly reduced. One explanation for these findings involves the selection of initial values for the gain variable. Selecting an initial value of gain is complicated by the fact that the relationship between gain and task difficulty is a U-shaped function, and this function shifts for every value of frequency. The initial value of gain used might have confronted the subjects with a difficult tracking demand located on the undersensitivity side of the U-shaped function. This problem would effect primarily the initial training sessions until higher and more convenient gain values could be attained; it might also slow down the general process of training. The experimental results of the gain-adapted group indicated this difficulty both in the first two trials of the training session and in a generally slower rate of adaption throughout the entire session.

The solution to how many adaptive variables to include is not straightforward. The present study included one stimulus-related and two response-related adaptive variables.

The seeming superiority of adapting stimulus variables suggests that the effects of type of adaptive variable must be separated from the number of adaptive variables. Additional research is needed in which the number of stimulus-related adaptive variables is manipulated. Given this restriction, however, there is some indication that an increase in the number of adaptive variables may effect the training process. With both frequency and acceleration, the highest values of the adaptive variable were obtained when only one variable adapted. The lowest values were obtained when three variables adapted, whereas two-variable combinations were in between. For the gain variable the three-variables condition yielded lower values of the adaptive variable than the two-variables condition. Although not reliable, the same trends appeared in both transfer and retention. Average RMS scores were consistently higher as the number of adaptive variables used in training increased.

Learning to Adapt

The comparison of experimental groups with regard to transfer difference scores yielded strong support for the hypothesis that adaptive training as compared with fixed-variables training facilitates the adjustment of subjects to changing conditions. The significant results obtained for both frequency- and gain-adapted groups suggest that this capability is to be attributed to the general experience of training under changing situations regardless of the final skill levels of learning curves. The significance of this new aspect of adaptive training is apparent for a wide range of operational situations in which a rapid readjustment of the operator to unstable or changing conditions is required. Ince and Williges (1974) demonstrated that although human operators can detect slow changes in system dynamics, they do not adapt perfectly. Perhaps various adaptive training procedures can be used successfully to enhance the human operator's ability to detect and adapt to slowly changing system dynamics. The results of this study certainly demonstrate some positive transfer in this regard.

Interestingly, both stimulus (frequency) and response (gain) adaptive training resulted in more consistent tracking in a changing transfer task. Even though adapting response variables does not appear to facilitate the rate of adaption in the response variable during training, positive transfer in terms of tracking error consistency does appear. None of these effects, however, appeared in the retention task. Either the training session was too short to affect prolonged transfer or the facilitating effects are rather short-lived.

CONCLUSION

This experiment should be regarded as an initial effort to demonstrate the importance of several variables in the use of adaptive training techniques. The research questions were attacked using a relatively short exposure to the various experimental conditions and a small number of subjects in each condition. Hopefully, more enduring effects would result from a much longer training session and larger samples. The present study, however, suggests a number of important implications in the use of adaptive techniques in perceptual-motor skills training.

ACKNOWLEDGMENTS

Contractual support for this project was provided by the Life Sciences Program, Air Force Office of Scientific Research, Contract Number F44620-70-C-0105. Dr. Charles E. Hutchinson was the scientific monitor of the contract. The authors wish to thank Douglas J. Collins for assistance with hardware and software requirements.

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